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THE EFFECT OF HELMET FORM ON HEARING: FREE-FIELD THRESHOLDS

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April 1972

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ABERDEEN PROVING GROUND, MARYLAND

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Statistically significant differences were found for all main effects and interactions. The experimental helmet was not significantly different from the bareheaded condition. The high-frequency attenuation characteristics of the M1 helmet were responsible for the statistically significant differences between head conditions. The differences are of little practical significance, however, since they fall within the range of variation most people experience on a day-to-day basis.

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CONTENTS

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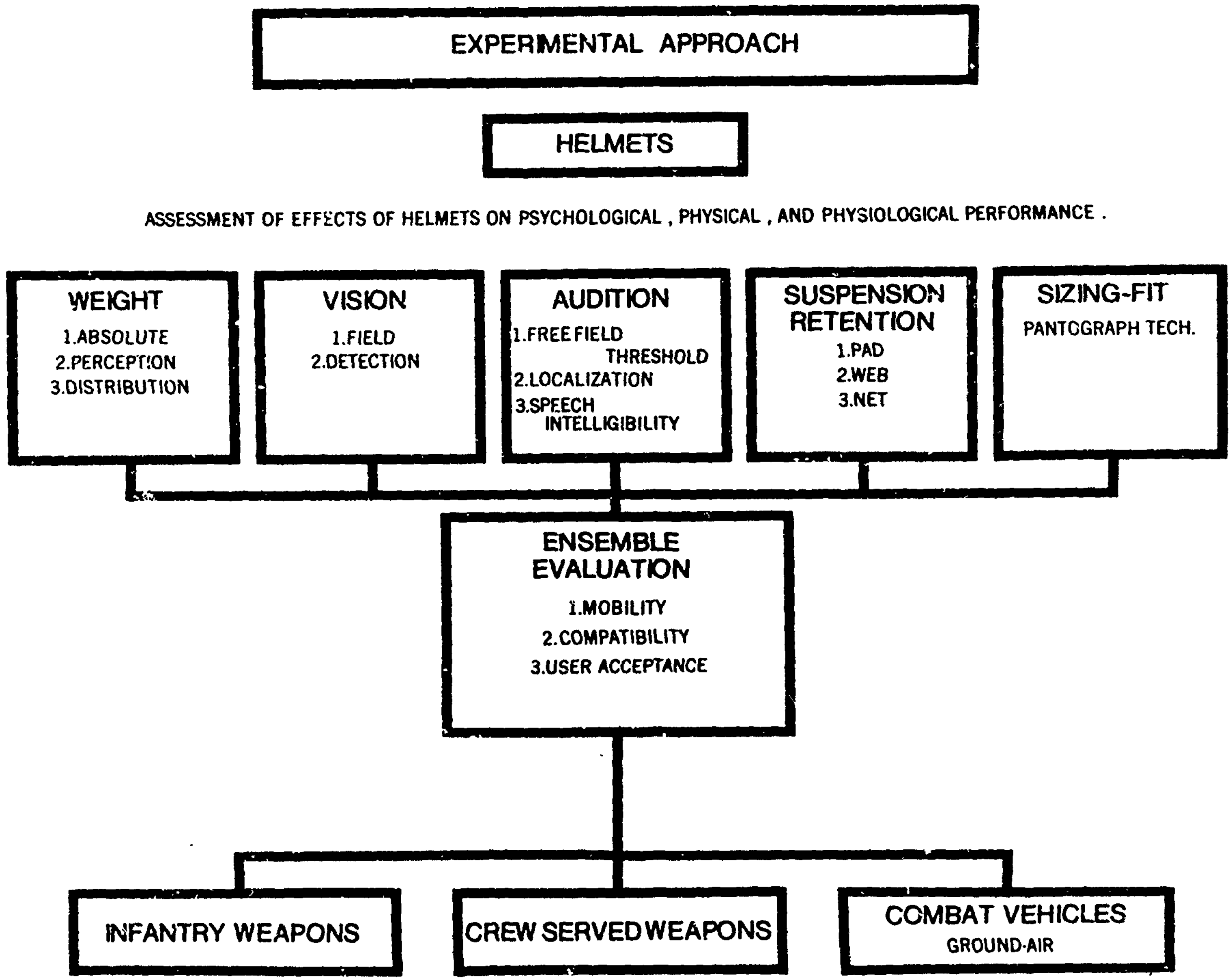

Fig. 1. HUMAN FACTORS EVALUATION OF INFANTRY HELMETS: EXPERIMENTAL APPROAC

THE EFFECT OF HELMET FORM ON HEARING:

FREE-FIELD THRESHOLDS

INTRODUCTION

The experiment described in this paper is one of a number of current and projected investigations aimed at developing comprehensive criteria for the evaluation of life-support systems. As a participant in the U. S. Army Materiel Command (USAMC) Five-Year Technical Plan for Personnel Systems (7), the primary responsibility of the Human Engineering Laboratory (HEL) is to provide a battery of standardized tests applicable to existing and prototype armor ensembles. The overall experimental approach shown in Figure 1 indicates that the standardized tests will ultimately be based on laboratory experiments and field studies, objective and subjective measures, and individual and group performances.

This report presents the results of the first phase of a three-phase program to determine the effects of helmet form on hearing.

This first-phase research is an attempt to quantify the increase in free-field hearing thresholds due to the wearing of headgear. Phases two and three will determine the effects on speech intelligibility and sound localization.

When a soldier wears his helmet, his audibility threshold may be raised, and he will perceive attenuation of audible signals. The amount of attenuation is likely to be frequency-dependent. The degree of external meatus (ear canal) occlusion may determine the extent of high-frequency attenuation due to formation of "sound shadows" (4). At the same time, the contour of the helmet rim may reflect high-frequency sound energy toward the ear and thus lower the threshold. Low-frequency sound waves will "bend around" the helmet rim with little or no attenuation. The threshold level will also depend on the angle between the axis of the external meatus and the source of sound. The first experimental helmet (Hayes-Stewart) has a unique configuration characterized by cut-outs which expose the external meatus and part of the pinna (external ear) (Fig. 2). Because of this exposure, both the presentation angle and tone frequency could be expected to alter the threshold level of the wearer.

The Hayes-Stewart helmet was designed to be close-fitting and therefore is furnished in nine sizes: three each in small, medium and large ranges. The close fit with a short standoff distance from the head results in a minimum unfilled volume which is relatively constant throughout the size range. The standard M1 helmet is furnished in but one size, so its unfilled volume varies considerably according to the size of the wearer. There is a small unfilled volume when it is worn by a large-headed man. A small-headed man must be able to see out from under the rim, so the helmet rides very high, with a corresponding increase in unfilled volume. Since the helmet is roughly hemispherical, there may be resonance effects or standing-wave formations which alter the "frequency response" of the helmet and are dependent upon the size of the wearer.

The four independent variables which were investigated were head size, type of headgear, tone frequency and angle of presentation.

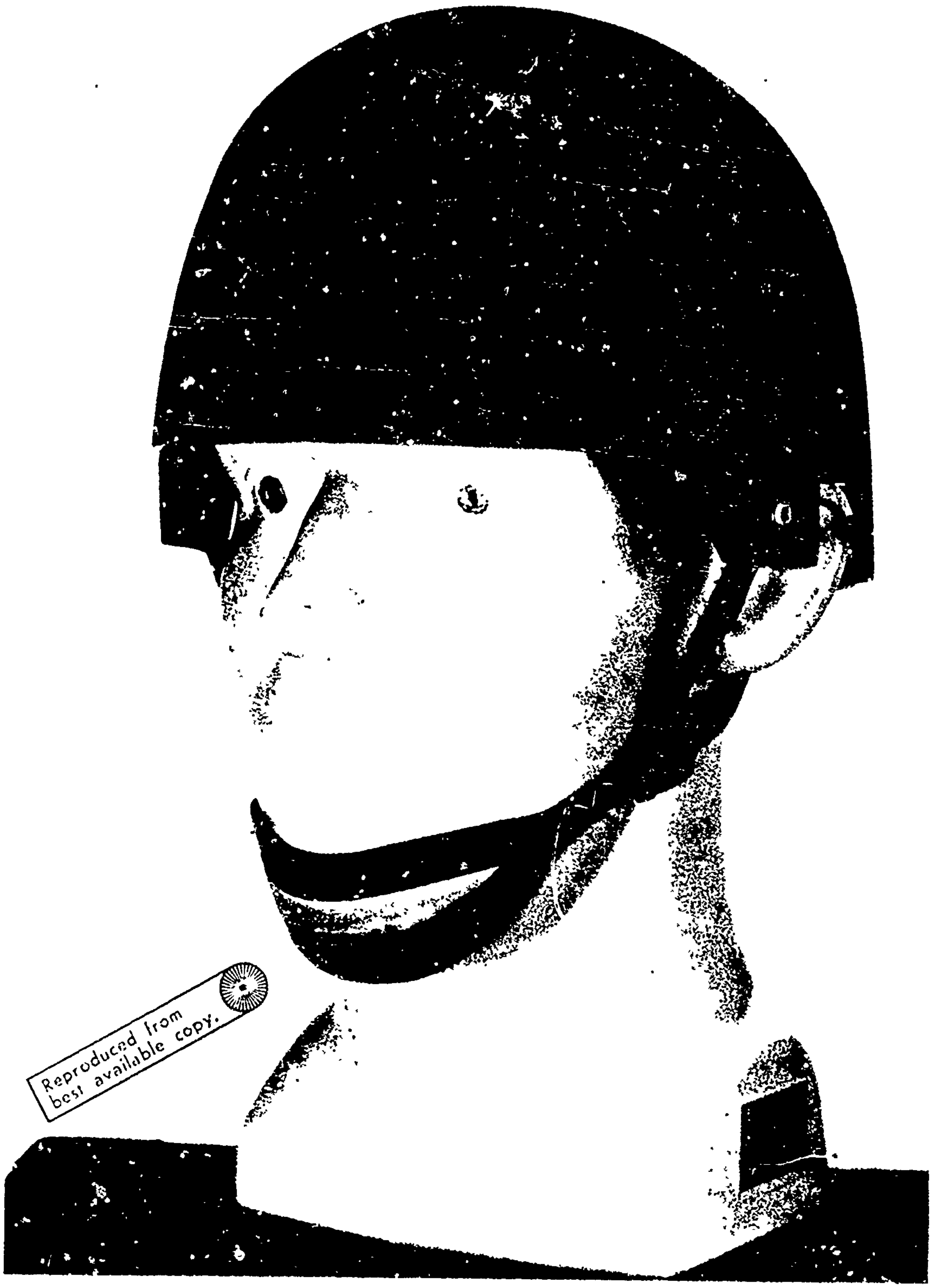

Fig. 2. HAYES STEWART HELMET

METHOD

To evaluate the amount of signal attenuation (or augmentation through reflection or focusing) the method of choice was to establish free-field audiometric thresholds for each of seven frequencies: 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. The tones were presented to the subjects (Ss) from five angles: zero degrees (S facing the sound source), 45 degrees, 90 degrees (source facing S's right ear), 135 degrees and 180 degrees (S facing away from source). The thresholds were determined for each frequency at each angle under three conditions: bareheaded (to establish for each S an audiometric baseline), a standard M1 helmet, and the Hayes-Stewart helmet.

Subjects

Twelve Ss were used in the experiment. These were both male civilian employees of HEL and enlisted men assigned to Aberdeen Proving Ground. Through a screening audiogram, they demonstrated that they had no more than a 10 dB hearing loss at the test frequencies (ASA Z24.22) (1). Four Ss were assigned to each of three head-size groups according to the Hayes-Stewart helmet which best fit them.

Apparatus

The Ss were seated on a special chair in an Industrial Acoustics anechoic chamber with a usable internal volume of approximately 480 cubic feet. The chair had a head and chin rest which located the center of the S's head two meters from an Acoustic Research AR-3 loudspeaker. The chair rotated about a point directly below the center of the S's head. It could be fixed at the five presentation angles (0 degrees, 45 degrees, 90 degrees, 135 degrees and 180 degrees). The test tones were generated by a model 440A Krohn-Hite oscillator. The frequency was verified on a Type 1191 General Radio counter. The tone was fed to a model 829E Grason-Stadler electronic switch with a 50-percent duty cycle. The tone was "on" for 500ms and "off" for 500ms. The interrupted tone was fed to a Type 1450-TAR General Radio decade attenuator for preliminary level control, then through a matching transformer (Grason-Stadler model E10589A) to a model E3262A Grason-Stadler recording attenuator. The signal was then fed through a McIntosh MC-75 amplifier to the AR-3 loudspeaker (Fig. 3).

Procedure

The von Békésy (self-recording) technique was employed to give a sensitive determination of audiometric threshold (5). The S held a switch which controlled the recording attenuator. When the S heard the tone, he pressed the switch which reduced the tone level. When he could no longer hear the tone, the S released the switch, which again increased the signal level. Thus, the S "bracketed" his threshold level as this task was repeated.

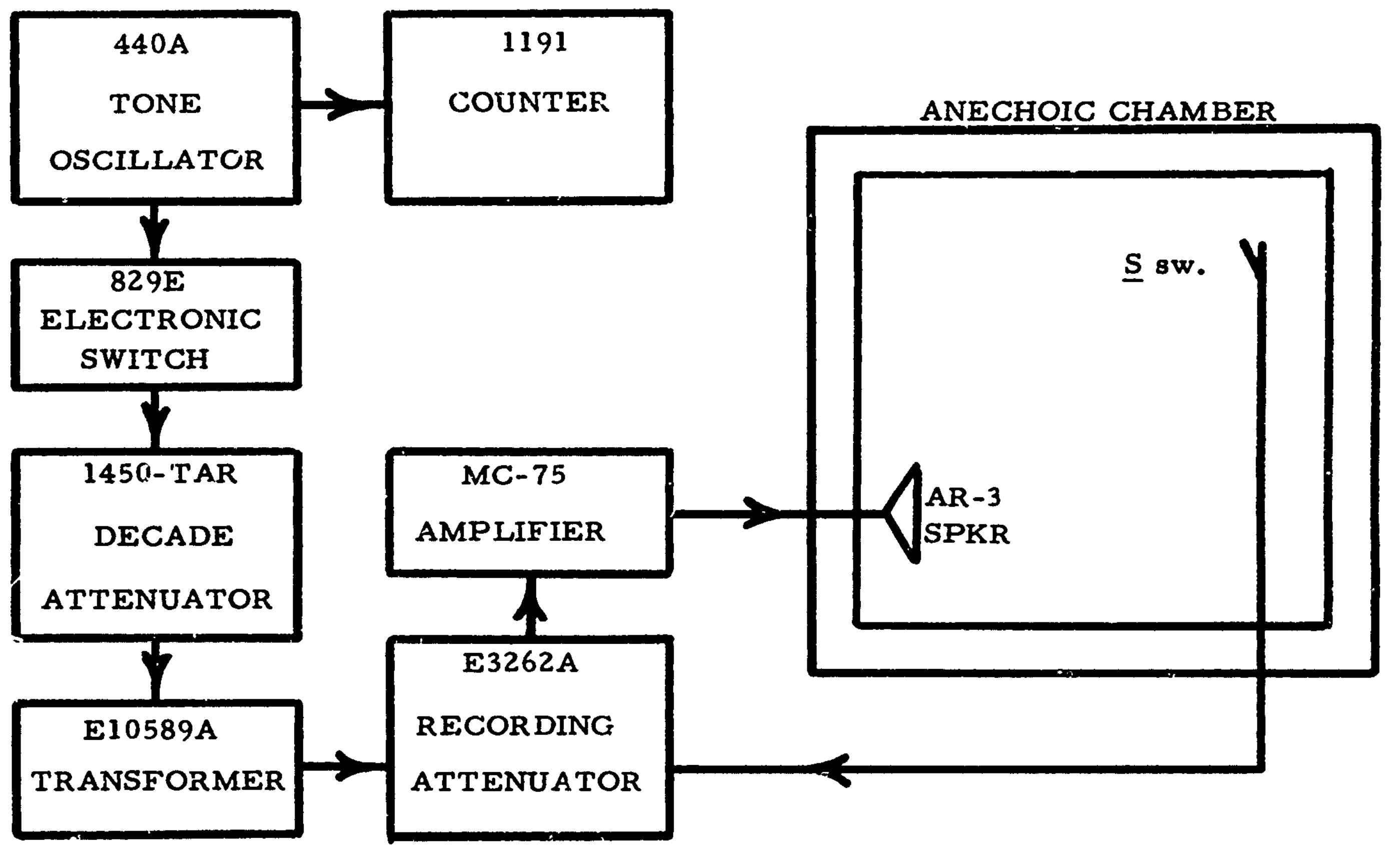

Fig. 3. BLOCK DIAGRAM OF APPARATUS

The Ss were seated one at a time in the anechoic chamber and were fitted with the first helmet in the series. The chamber was closed and the test period begun. After the seven tone thresholds were recorded, the S was fitted with a second helmet. This procedure was followed for all three head conditions.

The presentation order of the test tones, head conditions, angle of presentation and test period (there were four test periods in the morning and four in the afternoon) were randomized. During any one test period, the angle of presentation was fixed. Each S was tested once each morning and afternoon. Each S was tested three times under each condition over a 7 1/2-day period.

RESULTS AND DISCUSSION

Means were calculated from the three performance measures of each S at each condition. The data represent the Sound Pressure Levels (SPL's) in dB (re: 0.0002 μbar) at the center of the S's head. For performing an analysis of variance, the data were grouped in the following manner: one between-subjects variable (head size) and three within-subjects variables (head condition, frequency and angle of presentation). The between-subjects variable had three levels -- the three head sizes. Within-subjects variable 1 -- head condition -- also had three levels: bare, M1 helmet, and the experimental helmet. Within-subjects variable 2 -- frequency -- had seven levels corresponding to the seven test frequencies. The final within variable -- presentation angle -- had five levels: 0, 45, 90, 135 and 180 degrees (2).

The analysis of variance showed that the between-subjects differences were not significant, indicating that the unfilled helmet volume had no discernable effect on hearing thresholds. For ease of interpretation, the analysis was recomputed after dropping out the between-subjects variable and grouping all 12 Ss together. The results of the recomputation are shown in Table 1.

It can be seen that the differences due to head condition were significant at the .05 level. The remaining treatment effect differences as well as all interactions were significant at the .01 level.

Figure 4 shows the mean threshold levels in SPL for each of the seven frequencies.

The bareheaded-condition curve closely approximates the usual minimum audible field (MAF) found when testing young persons with good hearing (6). There is a band of increased sensitivity centered on 1000 Hz which extends from 500 Hz to 4000 Hz. It can be seen that there was very little difference between head conditions below 2000 Hz. Figure 5 more clearly shows the differences between the head conditions.

TABLE 1

Analysis of Variance

Source	DF	MS	F	P
Subjects (S)	11			
Head Condition (HC)	2	527.1	61.06	.05
Frequency (F)	6	13,280.8	48.55	.01
Orientation (O)	4	328.8	20.88	.01
HC x F	12	83.3	17.89	.01
HC x 0	8	57.4	13.74	.01
F x 0	24	76.6	10.63	.01
HC x F x 0	48	26.8	9.51	.01
Error				
HC x S	22	8.6		
F x S	66	273.6		
O x S	44	15.7		
HC x F x S	132	4.7		
HC x 0 x S	88	4.2		
F x 0 x S	264	7.2		
HC x F x 0 x S	528	2.8		

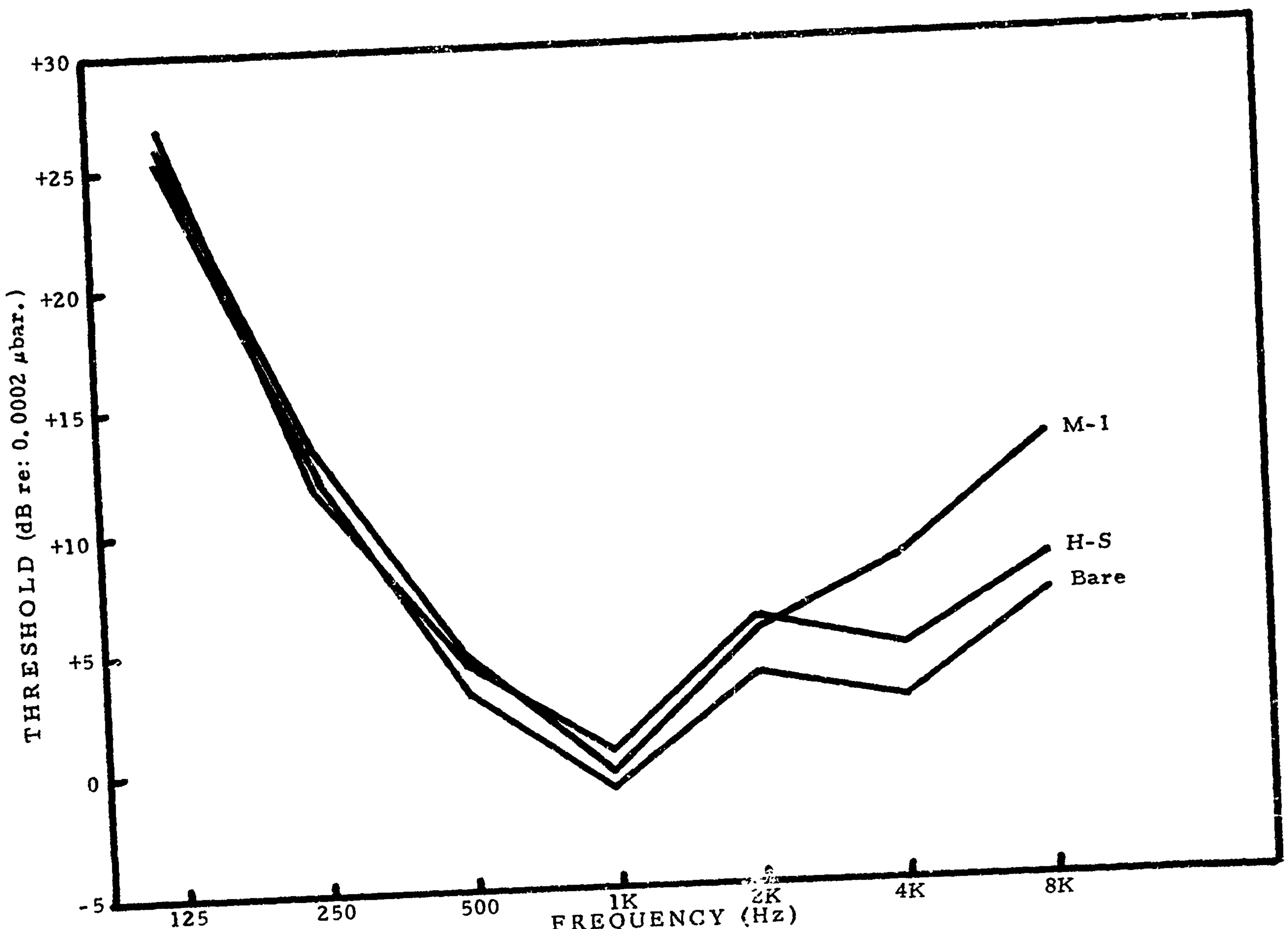

Fig. 4. EFFECT OF TONE FREQUENCY ON THRESHOLD

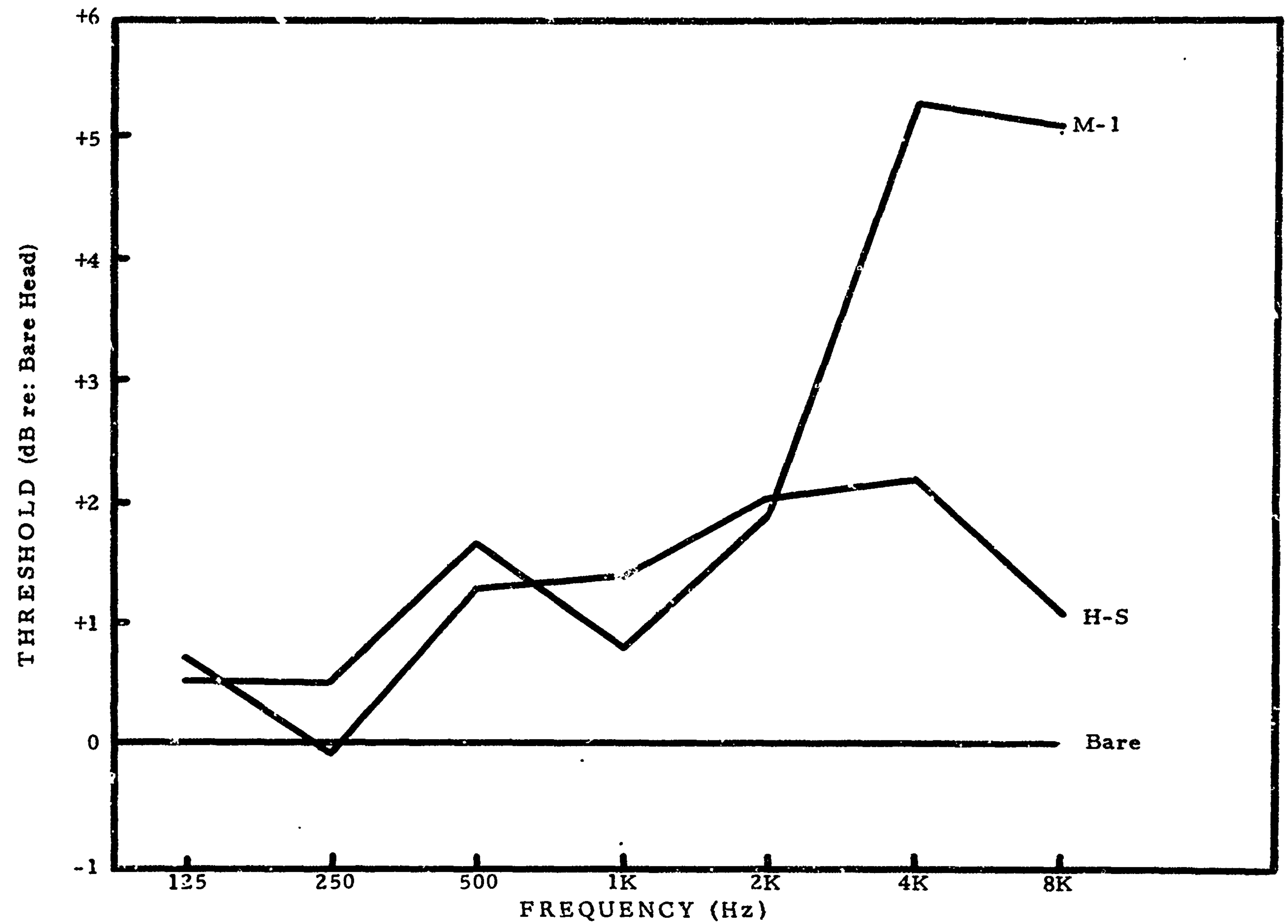

Fig. 5. DIFFERENTIAL EFFECTS OF TONE FREQUENCY ON THRESHOLD

To facilitate interpretation, the threshold levels obtained for the bareheaded condition have been plotted in a straight line as an "audiometric zero." The attenuation values for the two helmets were plotted to show the increase in threshold (or signal level attenuation) that arose from wearing the headgear. Again, it is obvious that there was very little low-frequency signal attenuation. The two helmets were extremely similar in their low-frequency attenuation characteristics, never being more than 0.6 dB apart. Up to 2000 Hz, there was still no greater than a 2.0 dB threshold increase over the barehead thresholds. High-frequency attenuation was more pronounced. At 4000 Hz there was a mean threshold increase of 5.3 dB for the M1 helmet, while the Hayes-Stewart threshold elevation was only 2.0 dB. At 8000 Hz, the Hayes-Stewart provided only 1.0 dB of attenuation, whereas the M1 threshold was raised by 5.0 dB.

Table 2 shows the results of the Newman-Keuls method of individual comparisons analysis of the high-frequency data (3).

TABLE 2

Newman-Keuls Analysis Summary

	Frequency (Hz)					
	4000			8000		
Head Condition	Bare	H-S	M-1	Bare	H-S	M-1
Bare	--	N.S.	*	--	N.S.	*
H-S	--	--	N.S.	--	--	*
M-1	--	--	--	--	--	--

* Significant at 0.05
N.S. -- Not significant

At 4000 Hz, the difference between the Hayes-Stewart helmet and the barehead condition was not significant. The M1 helmet was significantly different from the barehead, but not from the Hayes-Stewart helmet. At 8000 Hz, the Hayes-Stewart helmet was again not significantly different from the bareheaded condition. The M1 helmet was significantly different from both the Hayes-Stewart and bareheaded conditions.

Figure 6 shows the effect of presentation angle on threshold level.

When the Ss were bareheaded, their threshold levels were lowest when the sound source was directly facing the ear (90 degrees). The threshold levels were lower at the forward orientations (zero and 45 degrees) than at the rearward angles (135 degrees and 180 degrees) because of the configuration of the pinna with its resultant "sound shadows." The effects of the Hayes-Stewart helmet ear cut-outs can be inferred from Figure 6. Since the thresholds closely approximate those obtained in the bareheaded condition, resulting in a mean signal attenuation of only 1.2 dB, it appears that there was minimal disturbance to the near-head field of acoustic energy. The M1 helmet on the other hand, significantly altered the sound field around the wearers' heads because of the combined effects of high-frequency attenuation and sound-source rotation through the various orientations. At zero, the thresholds were the same as when the Ss were bareheaded. The threshold differences progressively increased as the sound source rotated, until they peaked at 135 degrees (45 degrees: 2.19 dB, 90 degrees: 3.41 dB, 135 degrees: 3.56 dB). At 180 degrees, the thresholds were 2.22 dB higher than those obtained from bareheaded Ss.

SUMMARY AND CONCLUSIONS

This investigation is an attempt to develop evaluative methodology for new items of personnel-armor systems developed under the AMC five-year plan. The evaluation of helmets is a three-phase effort, of which the determination of free-field audiometric thresholds is the first. Further studies will evaluate the effects of helmet form on speech intelligibility and sound localization.

Free-field thresholds were determined for 12 Ss under three head conditions at five presentation angles, for each of seven frequencies. Statistically significant differences were found for all main effects and interactions. The Hayes-Stewart helmet gave thresholds only slightly higher but not significantly different from those obtained in the bareheaded condition. The M1 helmet thresholds were essentially the same, except at high frequencies where the thresholds were increased. Although statistically significant, the differences between helmets appear to be of little practical significance, since they fall within the range of variation that most people experience on a day-to-day basis.

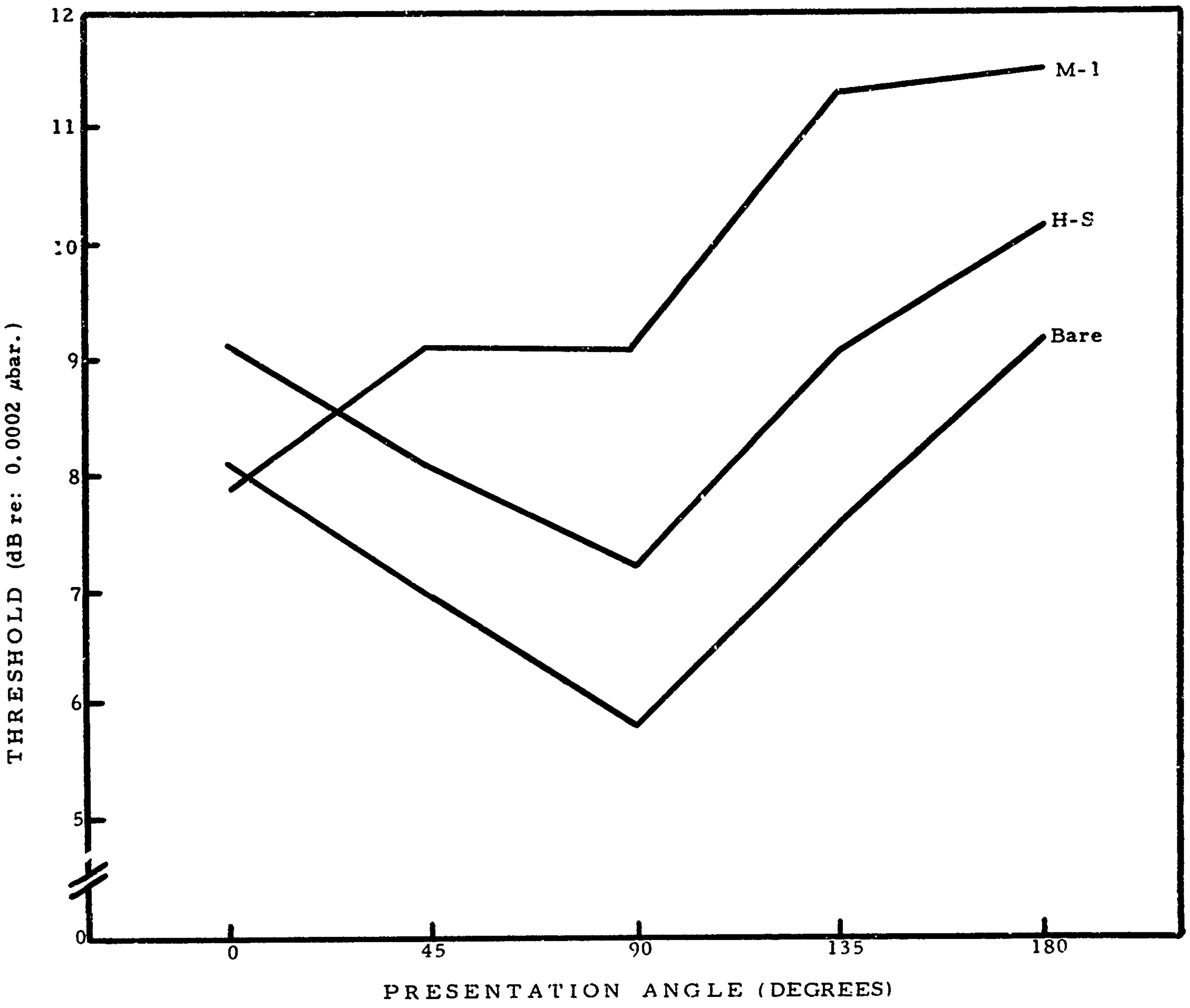

Fig. 6. EFFECT OF ORIENTATION ON THRESHOLD

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